Modular Advanced Composite Hull-form (MACH) Technology

Progress Report
Period October- December 2001

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Grant No. N00014-01-1-0916
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Report No. UM-MACH-PR-01-2

April 2002

TABLE OF CONTENTS

Page

1. Introduction

This progress report for the project Modular Advanced Composite Hullform (MACH) Technology covers the period from October 2001 to December 2001. The University of Maine (UMaine) has organized a coalition of University, Industry and Navy partners to develop innovative modular hull constructions techniques for fast surface ship and hybrid hull applications. The in this effort the University of Maine is partnered with Pacific Marine & Supply Co of Honolulu, HI (PACMAR), a pioneer in advanced ship hull form development, Applied Thermal Sciences Inc of Sanford, ME (ATS), an engineering research and development consulting company with extensive experience in innovative DoD projects, Nigel Gee and Associates of Southampton, UK, (NGA) a marine architecture firm with extensive experience in high speed vessel design. Technical expertise will be brought from the, NAVSEA Surface Warfare Center Bethesda, MD (NSWC-CD), Naval Sea Systems Command Undersea Warfare Center Newport, RI (NAVSEA Newport) are technical consultants throughout the program.

1.1 Objectives

The long-term objective of the proposed program is to develop and demonstrate hybrid composite /metallic structure joining concepts and technology for application to naval ship hulls. It is envisioned to develop hybrid joint concepts and technology that will have as broad of impact as possible on Navy vessels. The technology will be investigated for two types of generic hybrid construction: (a) the out-of-plane attachment of dissimilar composite and metallic structure (e.g., the attachment of composite panels to a supporting metallic framework) for the HYbrid Small Waterpalne Area Craft (HYSWAC) and (b), the in-plane attachment of dissimilar metallic and composite structure for the hybrid hull (e.g., the attachment or connection for a hybrid composite to metallic ship hull structure). The technology will be demonstrated at both the joint component level and at the hybrid system level. As a secondary objective, the smart skin concept for structural monitoring will be investigated as part of MACH, and the HYSWAC structural monitoring system will leverage the results.

1.2 Current Work

The primary tasks undertaken during this period include:

1. Continuing work on connections.
    a) Development of a plan for study of stress relaxation in bolted connections
    b) Development of a plan for study of adhesives in hybrid connections in conjunction with the AHFID program.
    c) Study of the Structural Response of Connections
    d) Manufacturing processes for composite panels.
    e) Methods for fabrication of co-cured hybrid connections.
2. Research and planing for cavitation erosion protection study.
3. Continuing work on structural monitoring systems.

4. Construction of Single H-body for WAVERIDER.
5. Completion of the design of the H-body for HYSWAC.

2. Connection Studies

2.1 Stress Relaxation in Bolted Connection

The objective of this effort is to quantify the stress relaxation of transversely compressed composites in single bolted aluminum/vinylester hybrid connection, where used where watertight seals are required. It is proposed to study similar joints at a sub-component level. From this information it can be determined which joint is best suited for the specific application. Research is proposed to study the effects of the following:

1. Effect of bolt torque and geometry,
2. Effect of stress concentrations
3. Effect of varying thickness on the constituents
4. Effects of re-applying torque to the bolts
5. Temperature/Moisture Effects

In order to study the effects of stress relaxation on E-Glass/Vinylester composites, several tests are proposed. One group of tests will be done with a compression block fixture. This test will be used to quantify the stress relaxation of the vinylester composite in the transverse direction while being subjected to a relatively uniform stress state through the thickness. Another group of tests are proposed to study the effects of stress concentrations and retorquing of bolts on stress relaxation response in Aluminum/E-Glass Vinylester single bolt hybrid connection sub-componentss. A third group of tests will be used to study effects of tapered head bolts vs. non-tapered head bolts on single bolted connections. Finally a series of test with multi-fastener rows will be performed.

2.1.1 Compression Block Test.

This group of tests will be used to quantify the transverse stress relaxation of the Vinylester composite under relatively uniform stress. The fixture consists of two large steel blocks, with a composite sample being compressed between the two. The test coupon is a square, 2 inches by 2 inches, with constant thickness. The fixture has bolts at its four corners to provide the load.

2.1.2 Single Bolt Sub-component Tests.

These tests will be used to study the effects of stress concentrations and reloading of the composite on stress relaxation. This data will be used to assess the watertight seal in the connection for applications on ship hulls. The test fixture consists of a plate of aluminum bolted to a flat composite coupon. Bolt diameter used will be equal to the plate thickness and the dimensions of the metallic and composite plates are five times the plate thickness. The plates are then bolted together using bolts with internal strain gages in them. . The maximum pressure distribution in the connection will be determined using pressure paper.

2.1.3 Multi-bolt Sub-component Tests.

A series of tests with multiple rows of fasteners will be developed to assess the influence of highly variable stress state on bolt relaxation. These tests will be closest to real world applications. A series of instrumented fasteners will be used with pressure paper to evaluate the response.

2.1.4 Analysis

Non-linear Finite Element Analysis (FEA) will be performed to study the stress relaxation in the connections. Non-linear models will include the effects of viscoelastic material and contact. The models will be correlated to test results and used subsequently in parametric studies to ascertain the response of bolted joint. The rationale here is that conducting stress relaxation testing is very time consuming and costly. A proper mathematical will held researchers and designers determine the effect of changing parameters such as geometry, material properties, and loading state without having to wait months for tests results.

2.1.5 Test Plan Development

A detailed test plan for this effort is in the process of being developed. This plan will include specific details regarding the test articles, test setup, test matrix, test procedures, instrumentation and data analysis.

2.2 Study of Adhesives in Hybrid Connections

The University of Maine is in the process of performing and adhesive study as a combined effort between the MACH and AHFID programs. To understand the adhesive requirement needed with a large bond line thickness, compared to aerospace tolerances, it is proposed to study similar bonds at a sub-component level under loads of tension, shear, and flexure.

A study is proposed to:

1. Provide baseline data that will guide adhesive selection,
2. Quantify strength of the adhesive connections,
3. Quantify the effect of bond line thickness,

4. Quantify the effect of various connection geometry's
5. Quantify the effect of the surface preparation
6. Quantify the effect of the environment.

Geometries to be investigated are: a) single lap-connection, b) scarf joint and c) notch connection. These joint types are depicted in Figure 2.1.

2.2.1 Adhesives

A total of six adhesives will be studies as follows:

1. **Belzona 1121** is a two-component paste grade system based on a silicon steel alloy blended with high molecular weight reactive polymers and oligomers. Belzona 1121 was selected because of its ease of application, it's relatively easy to work with, and it's relatively low cost. For ease of application this material has an extended working life. Once cured, it is durable and fully machineable. Another advantage is that the Belzona product is an odorless epoxy so it can be applied in any environment.
2. **Loctite (Hysol) 9359.3** is a two-component aerospace grade structural adhesive, which exhibits high peel and high tensile lap shear strength. A variety of substrates such as metals, thermoplastics and composites may be bonded with this product. Loctite 9359.3 was tested by Spencer composites and recommended for use in the AHFID project. This epoxy is a high-end epoxy, which is very expensive and relatively hard to work with.
3. **Loctite 9394/2** is a two-component structural adhesive. Loctite 9394/2 epoxy ranked high in an adhesive study conducted by Harrison and Crichfield [2001]. **Loctite (Hysol) 9430** is a modified epoxy adhesive that attains structural properties after room temperature cure. This two-part adhesive is formulated to give very high peel strength coupled with excellent shear strength. The tough, flexible nature of this adhesive makes it useful for bonding dissimilar substrates and for assemblies requiring bond line thickness up to one-tenth inch. The Loctite Corporation as a substitute recommended the Loctite 9430, which would be less expensive than the 9359.3 yet provide similar properties.
4. **SIA E2119** is a 1:1 two-component toughened epoxy adhesive that will achieve handling strength in less than 8 hours and full cure in 72 hours at room temperature. It can be gelled in 4 minutes at 180^{o}F and post cured at room temperature or at elevated temperatures. Uses include bonding metal, plastic, FRP and composite materials. E2119 is an excellent candidate where shock and impact resistance are needed..
5. **3M 2216** is a flexible, two-part, room temperature curing epoxies with high peel and sheer strength. 2216 meets MIL-A-82720 and is excellent for bonding many metals and woods, most plastics and rubbers, and masonry products. This adhesive also ranked high in an adhesive study conducted by Harrison and Crichfield [2001].

2.2.2 Bondline Thickness

Bondline thickness experienced in Naval applications are typically greater than those found in aerospace. Tests with bondline thicknesses of 0.1", 0.25" and 0.35" will be performed.

2.2.3 Surface Preparation

Durable adhesive bonds between metal-to-metal or metal-to-composite can be obtained reliably only through proper selection and careful control of the materials used and the steps in the bonding process. The preparation of the metallic substrates to obtain surfaces with appropriate characteristics is a critical step. Improper surface preparation can produce seemingly acceptable bonds that can degrade rapidly with time.
It is proposed that the surface preps used in this test are:

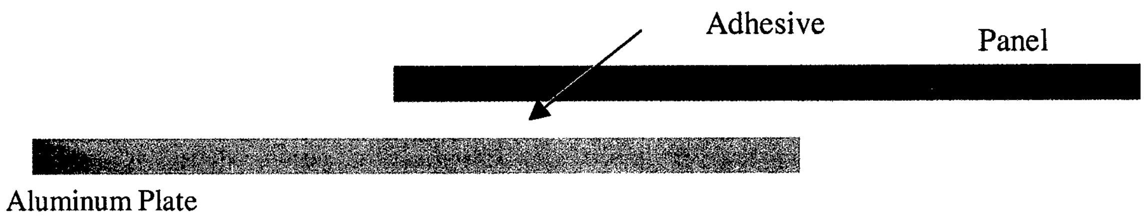
a. Mechanical Surface Prep (Sanding/Cleaning)
b. Grit blasting (3-5 mil blast profile)
c. Silane or Acid Etch

Environmental effects have a significant influence on adhesive performance. Specimen conditioning pertains to temperature and moisture conditions at the time of testing. Conditioning will be as per ASTM D5229. A summary of test conditions is as follows:

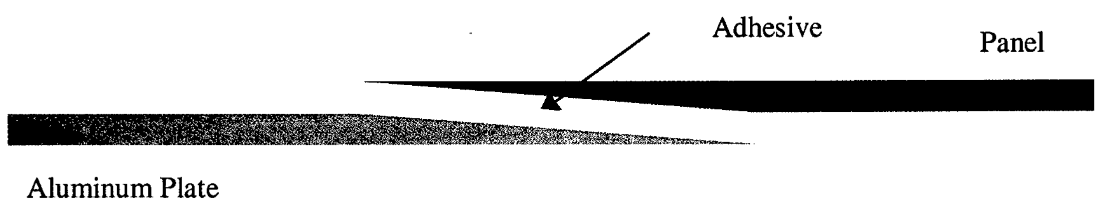
1. RT – Room temperature of 73.4° +/- 3.6° F
2. ET – Elevated temperature 140° F +/- 3.6° F
3. D – Dry moisture conditions – conditioned at 50% RH and 73.4° +/- 3.6° F
4. W – Wet moisture conditions – conditioned at 98% RH and 150° F until specimen weight stabilizes.

2.2.4 Test Plan Development

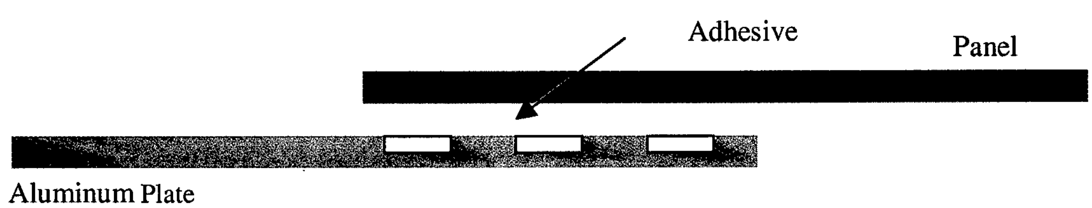
A detailed test plan for this effort is in the process of being developed. This plan will include specific details regarding the test articles, test setup, test matrix, test procedures, instrumentation and data analysis.



a) Single Lap Joint



b) Scarf Joint



c) Notch Joint

Figure 2.1 – Connection Types Used in the Adhesive Study.

2.3 Structural Response of Connections

Work on structural response of connections is ongoing. A decision was made to study issues with the simpler joints first. This occurred during a Sept. 2001 meeting between UMaine, NSWC and ATS. A study of connection response is initiated with the bolted connection, followed by the bolted close-out and embedded metallic insert. A test plan will be developed to study connection response at the sub-component level.

Testing including flexure, tension, and compression of subcomponents will be conducted at room temperature. The test articles will consist of beams with representative panel cross sections and representative interface attachment configurations. The tests will demonstrate performance of the panel design configuration and processes under mechanical loading conditions and will provide a design envelope for analysis of the critical panel configurations, the panel and metal framework attachment. In addition, the tests will verify panel analysis models.

Sub-component testing will be conducted to evaluate critical panel configurations, such as the panel attachments, embedded hardware and tapering, where justification of performance is required by test. Sub-component testing will demonstrate panel performance under critical operating environments and support verification of analysis models. Sub-component configuration testing will demonstrate performance of design configuration and processes under mechanical loading, support verification of analysis models and provide design envelope for 3-D panel analysis. These are a precursor to the more costly 3-D panel testing.

The scope of the sub-component testing involves experimental testing and finite element analysis of hybrid connection sub-components assemblies.

2.4 Composite Panel Fabrication

2.4.1 Materials

Materials selected for preliminary panel fabrication studies are BTI 24 oz. 0-90 knit E-glass fabric and an SGI 24 oz. +/-45 E-glass knot fabric. Resins considered are vinylesters and include Dow Derekane 411-C50, and Derekane 510a which is a fire retardant resin.

2.4.2 Flat Panel VARTM Setup

Vacuum assisted resin transfer moulding (VARTM) process was selected as the manufacturing process due to its strong endorsement by the NAVY. SCRIMP™ is a patented form of VARTM. The VARTM setup at the Mechanical Engineering Department's Crosby Laboratory is depicted in Figure 2.2. This system includes a glass bench top, a 2.5 HP Welch vacuum pump, resin canisters and other miscellaneous equipment. The system is capable of fabrication of flat panels up to approximately 3ft. x 7ft. Figure 2.3 shows a large flat panel being manufactured and 2 smaller panels being fabricated simultaneously. Figure 2.4 show a view of various thickness parts.

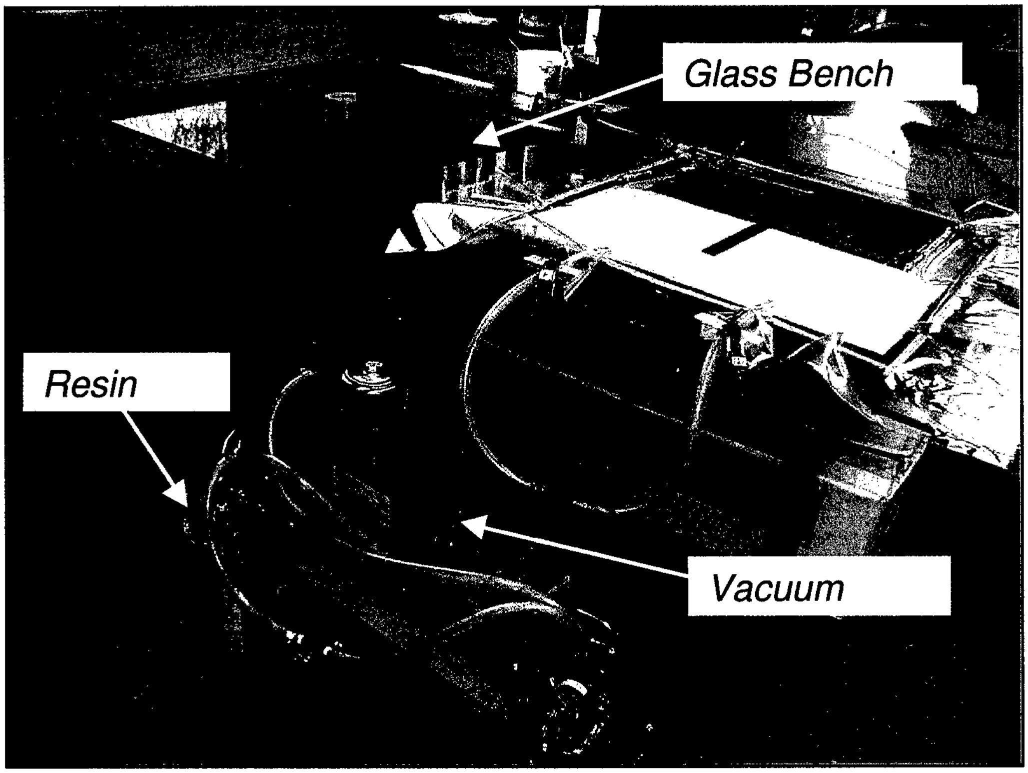
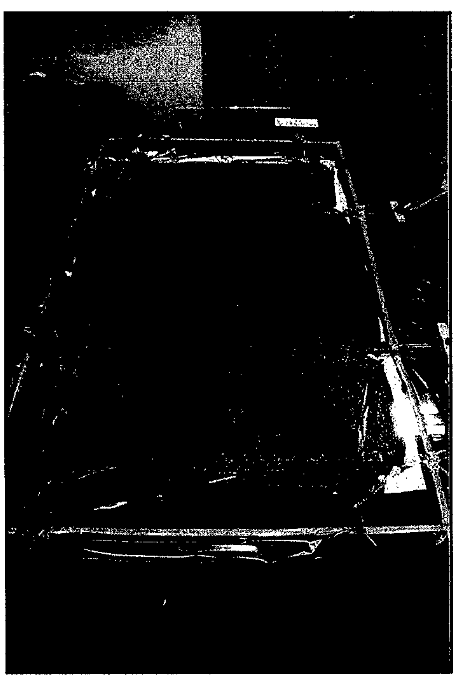


Figure 2.2- UMaine Crosby Laboratory VARTM Setup



Ability to infuse multiple panels simultaneously for different applications

Figure 2.3 – Flat panels being manufactured.

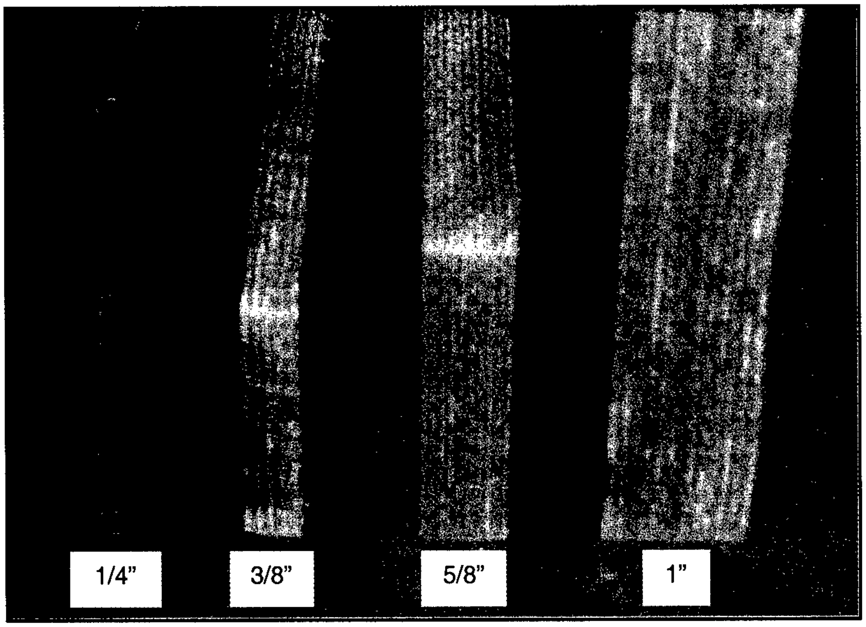


Figure 2.4 – End view of various thickness parts

3. Structural Monitoring

Structural monitoring and evaluation techniques are under investigation for the following purposes:

1. Verify structural integrity of the hybrid connections,
2. Quantify strain and vibration using embedded sensors ,
3. Monitor the local environment for deleterious effects such as moisture intrusion, adhesive debonding
4. Develop systems that minimize panel cabling.

Planned is a hybrid system of sensors to meet different monitoring requirements for evaluation of connection and panel integrity. A summary of sensor possibilities is given below:

- **Water Ingress**
  - Long Period Grating (LPG) fiber optic sensors
  - Fiber Bragg Grating (FBG) sensors

- **Excessive Strain & Delaminations**
  - Extrinsic Fabry Perot (EFP) fiber optic sensors (static)
  - Fiber Bragg Grating sensors (dynamic)
  - Piezo-Ceramic (PZT) sensor/actuators

- **Adhesive Bond Integrity**
  - Non-Linear Ultrasonics (UT)

- PZT sensor/actuators

3.1 Embedded fiber optic sensors

Because of their relatively low system cost and ability to evaluate in a static situation against conventional foil type strain gages the study on embedded fiber optic sensors was performed using the EFP type. A typical sensor embedment is shown in Figure 3.1. This was performed in UMaine's ASC laboratory.

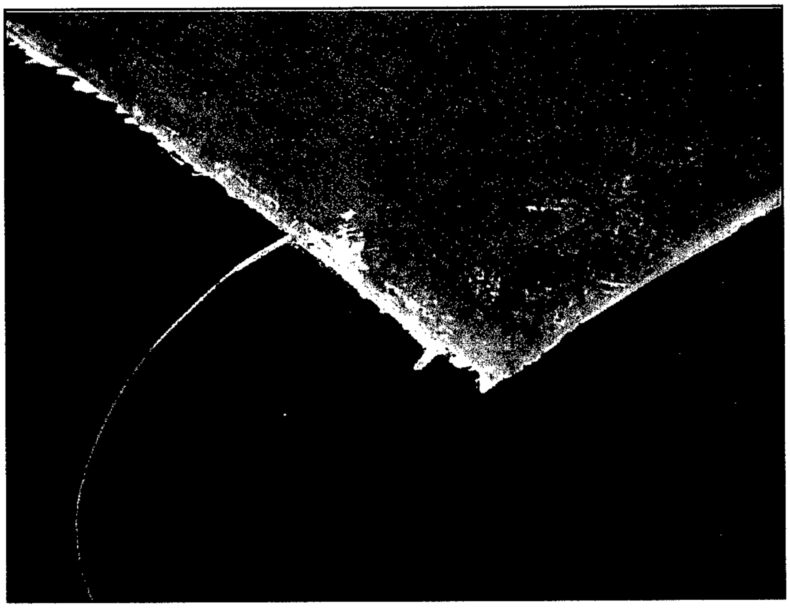


Figure 3.1 – Embedded EFP sensor in a Eglass-vinylester panel.

The current status of this research at UMaine includes a comprehensive literature review to determine embedment method of sensors which has been completed. Procurement and implementation of fiber optic sensors and monitoring system. (Luna Innovations Extrinsic Fabry Perot, EFP sensors). Embedment of sensors in structural test articles fabricated by SCRIMP is in progress. Finite element modeling of the sensor/composite interface is beginning. Plan for completion of this work in the form of a master's thesis is by July 2002.

3.2 Piezoelectric Sensors

This work includes piezoelectric materials integrated with composite panels. A system for automated in-situ modal testing is under development to quantify change in natural frequencies and damping due to connection response. This study also includes FEM of curved panels with embedded piezoelectric actuators/sensors.

Figure 3.2 shows a schematic of a system for assessment of the dynamic properties of a panel/connection system. This includes a signal generator and power supply for excitation of the piezoelectric actuator and PC based data acquisition and analysis system. An OMETRON laser vibrometer is used for verification of the dynamic properties of the test panel. Embedded sensors and actuators are being used to determine the natural frequency and damping coefficients of a composite panel. A structural monitoring system that assesses the health by comparing the dynamic response of damaged and undamaged composite panels is being developed. The optimum locations for the sensors and actuators are chosen using Finite Element Models.

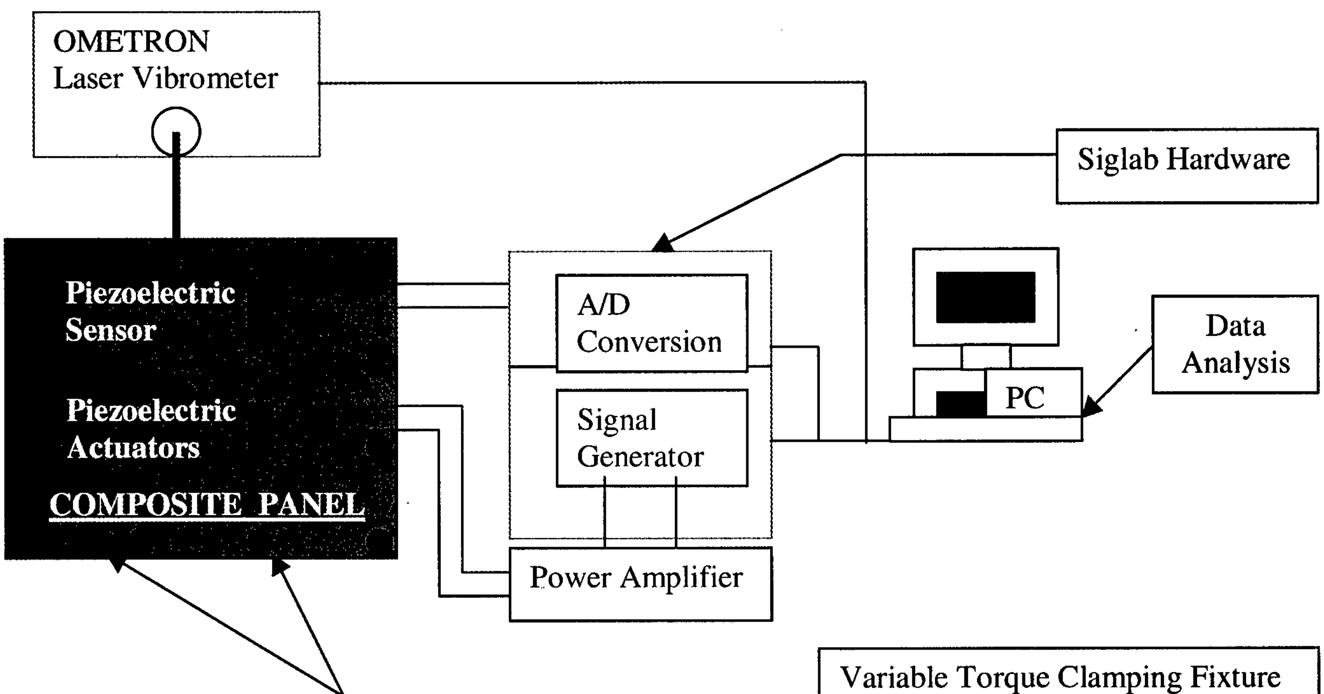


Figure 3.2 – Assessment of Panel Dynamics Using Piezoelectric Sensor/Actuators.

3.3 Non-Linear Ultrasonic Inspection

Non-linear ultrasonic inspection is a potential method to inspect bonds integrity between dissimilar materials. With this technique a specimen is excited by a high power, relatively low frequency transducer and the response is measured. Defects result in increased harmonic content of received signal. This technique will be evaluated, in a preliminary manner, for evaluation of adhesive bondline properties and to develop characterization methods that are suited for evaluation of adhesive response.

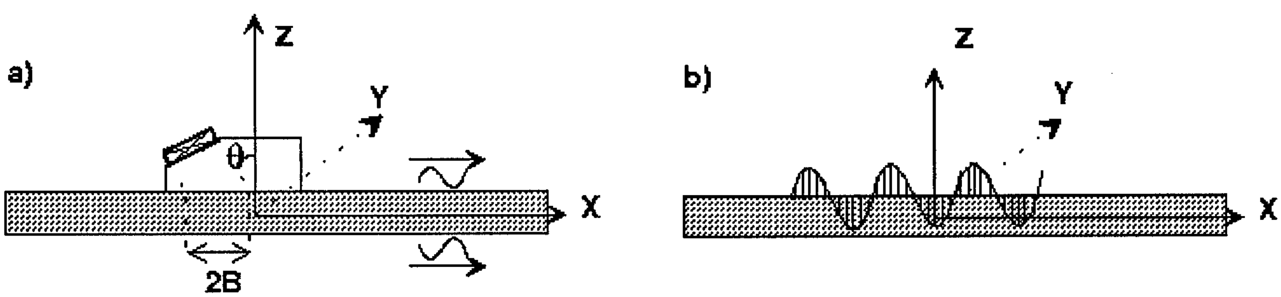


Figure 3.3 – Non-linear UT Methods.

3.4 Intra Panel Processing

Techniques for implementation of inter panel processing of data signals are being looked into under this project. The goals for the IPP are to control & monitor numerous sensors on or in a panel using a small number of external connections and small physical size. The system should be suited to a wide variety of sensor inputsa and should connect to the external world in a simple way.

The choice of microcontroller includes criteria such as: 1) Low cost; 2) Large number of I/O lines; 3) High speed; 4) Networkable; and 5) Low power required. Selected for this purpose is a Rabbit Semiconductor RCM 2200 Microcontroller/board (see Figure 3.4). This board has a small size - 59 x 49 x 22 mm *(including connectors)*, Built in IEEE 802.3 10 Base-T Ethernet TCP/IP protocols, built in 26 I/O lines, 256K Flash 128K SRAM. Its cost is in the neighborhood of $50.

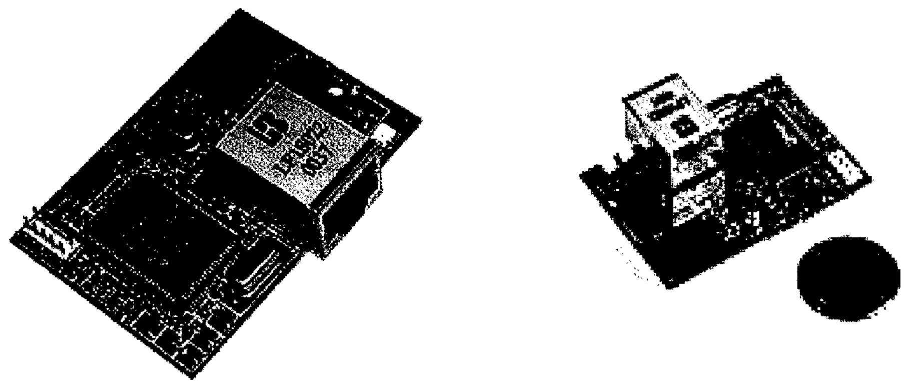


Figure 3.4 – Controller for Data Networking

4. Cavitation Erosion Protection

4.1 Task Description

This task comprises an engineering study that focuses on methods of erosion control and impact resistance of composite panel structures as lead by Ken Light of ATS. A number of advanced material system concepts will be investigated, including but not limited to:

- Composite shell overlaid with a metallic skin
- Composite shell with cladded metal or ceramic coatings
- Advanced durable composite shell

Initially, an assessment of the state of the art in cavitation and erosion protection was performed. This survey included methods for qualifying various material systems with respect to cavitation-erosion. Testing methods were investigated and subsequently resulted in the formulation of a test plan to verify the performance of the chosen surface protection method(s).

Based on the results of this survey, the constituents for the composite shell, erosion protection overlay and any intermediate interface layer shall be evaluated and one or more candidate material systems will be designed. As part of the evaluation process, attention will be given to the full scale manufacturing process of any potential design.

4.2 Background Research on Cavitation Erosion

A large volume of information exists in the literature regarding the understanding of the basic phenomena associated with cavitation erosion. In the literature, the greatest amount of work done on the erosion resistance of composite materials comes from rain erosion tests in the aerospace industry. There are some parallels to be drawn between these two environments and it has been cited that the methods used to improve the performance are essentially the same.

In order to understand a material's response to cavitation attack, it is necessary to first understand the basic mechanisms of cavitation. The term cavitation refers to the phenomena of the formation and collapse of vapor bubbles within a liquid. When the pressure in a fluid drops below the vapor pressure of the liquid, then a bubble is formed. Once the liquid pressure recovers, the bubble collapses and emits both a shock wave and liquid jet due to asymmetrical collapse as shown in Figure 4.1. If the bubble is near a solid boundary, then this liquid jet acts as a "water hammer" against the surface. Although both of these mechanisms can result in damage to the structure, the majority of investigators credit the "water hammer" as being the major damage mechanism. In addition to the effect of a single bubble collapse, the idea of magnification in impingement pressure due to the cumulative collapse of a cloud of bubbles has been reported as providing as much as a ten fold increase in pressure. Pressures on the order of 900 MPa have been reported at the surface near a cavitation cloud. The effect of this phenomenon on ductile materials is a local strain hardening at the sight and eventual embrittlement of the material. Further exposure beyond this incubation period leads to cracking and loss of material.

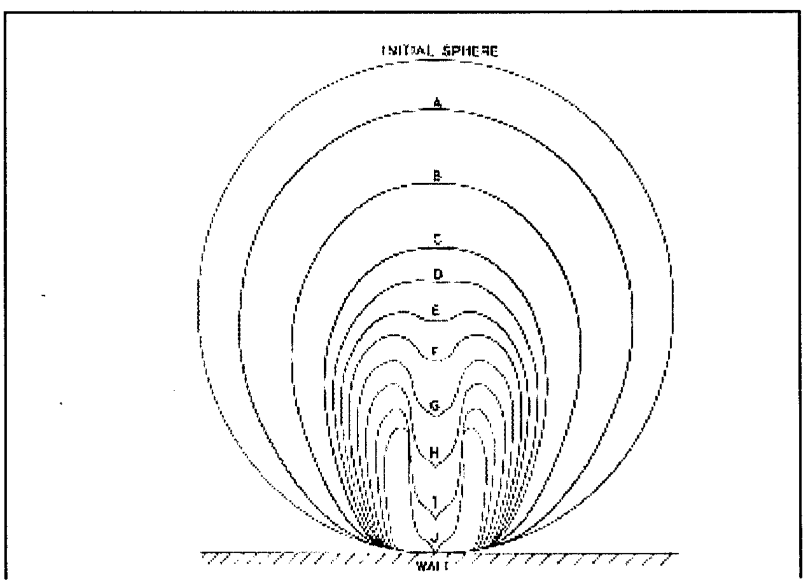


Figure 4.1 – Schematic of asymmetrical bubble collapse showing liquid jet impingement, [after Plesset].

There have been numerous studies that have attempted to correlate a material's cavitation erosion resistance with physical properties such as hardness, strength, or energy absorption characteristics. These studies have met with varying degrees of success. Each study will cite a specific material which defies explanation. With that being said, the majority of authors report that the strength properties of a material dominate the resistance to this form of attack. This is followed closely by the energy absorption and elastic properties of a material. Studies that have specifically focused on the response of composite materials have shown that the matrix material of any composite is the first to fail. This agrees with the previous statement noting that the matrix is the low strength constituent of the composite material. There has been some success, however, with one study reporting that a sandwich composite system composed of an E-glass/Epoxy/PVC foam core sandwich laminate achieved an erosion resistance better than that of 316 stainless steel.

4.2.1 Impact

The mechanism of loading a structure due to impact involves the transfer of kinetic energy of the impinging particle to the structure. In quantifying the kinetic energy, the mass is the mass of impinging particle and the velocity is the relative velocity of impact.

In order to design an impact resistant structure, one must be able to absorb the kinetic energy of the particle while not exceeding the strength limits of the material. In a sense, impact is the macroscopic version of cavitation with the particle impact being analogous to the impingement of the liquid jet from cavitation. It can thus be argued that a material system that provides good cavitation erosion performance will contain the necessary mechanisms to also providing for good impact resistance of reasonable magnitude.

4.3 Material System Design

Based on a review of the cavitation erosion and impact mechanisms of loading a structure and a recent review of the use of composites in the marine industry, the following material systems are presented for initial design, construction and testing. It is anticipated that the lessons learned in this first round of testing will lead to performance modifications and/or new material system designs. Table 4.1 shows a qualitative ranking of various component properties.

4.3.1 Fiber Type

The initial selection of fiber types for testing is based on a review of recent marine industry practices of both recreational and commercial vessels. These fiber types provide a broad range of physical properties in order to tailor the end structural properties and are all compatible for use in the marine environment. When applicable, a particular grade or subtype of fiber has been specified. The initial list of candidate fiber types is as follows:

- E-Glass
- Carbon Fiber – PAN (T300)
- Aramid Fiber (Kevlar® 49)

Table 4.1 – Qualitative assessment of marine composite construction materials, [after Greene, 2000]

	Fiber			Resin					Core					
	E-Glass	Kevlar	Carbon	Polyester	Vinyl Ester	Epoxy	Phenolic	Thermoplastic	Balsa	Cross Link PVC	Linear PVC	Nomex/Alum Honeycomb	Thermoplastic Honeycomb	Syntactic Foam
Static Tensile Strength	■	■	■	□	□	■	□	□	■	■	■	□	□	□
Static Tensile Stiffness	□	■	■	□	□	□	□	□	■	□	□	■	□	□
Static Compressive Strength	■	□	□	□	□	□	□	□	■	□	■	■	□	□
Static Compressive Stiffness	□	□	■	□	□	□	□	□	■	□	□	■	□	□
Fatigue Performance	□	■	■	□	■	■	□	■	■	□	■	□	■	□
Impact Performance	■	■	□	□	■	■	□	■	□	■	■	□	□	□
Water Resistance	■	□	□	□	■	■	□	■	□	■	■	□	□	□
Fire Resistance	■	□	□	□	□	□	■	□	■	□	□	■	□	□
Workability	■	□	□	■	□	□	□	□	■	□	□	□	□	■
Cost	■	□	□	■	□	□	□	■	■	□	□	□	■	■
	■ Good Performance □ Fair Performance													

4.3.2 Resins

The initial resin selection is based on a review of the compatibility with the fiber and the marine environment. These resins have also been reported as having good properties with respect to strength, fatigue and energy absorption. The candidate resins types are:

- Vinyl Ester (Derakane 411)
- Rubber Modified or Thermoplastic toughened Epoxy

4.3.3 Sandwich Core Materials

The sandwich cores selected here have been shown to have a good mix of strength and/or energy absorption properties. The initial candidate core materials are:

- Balsa
- Linear PVC (Airex R62.80)

4.3.4 Laminate Geometry

The laminate geometry implies a mixture of ply thicknesses (thick or thin) and/or weave densities at the surface. Work on rain erosion studies of aerospace composite materials has yielded an interesting fiber orientation result. In this scenario, the ends of the fibers are perpendicular to the surface of the laminate. This orientation provides for good energy transfer through the fiber from the impacts. This orientation will have to be evaluated for manufacturability.

4.3.5 Surface Treatments

This category provides a number of different options including cladding, sputtering or spraying on of various metals or polymers. These coatings will be thin and are intended to provide a surface shield of the matrix material. Specific metals and coatings as well as application techniques are still being investigated.

4.3.6 Metal Skins

This material system provides for a composite panel overlaid with a thin metallic skin. The thickness of this skin is anticipated to be on the order of 0.0625 inches. The challenge with this system will be the energy transmission characteristics across the bond line with the composite panel. Initially, a bond using the existing matrix material will be evaluated, but systems which incorporate a resilient layer are also a possibility. The metals that will be evaluated for this task may include NiAl bronze (propeller bronze) as well as some extremely corrosion resistant duplex stainless steels. Two examples of these are ferralium (alloy 255) and Zeron 100.

4.4 Future work on cavitation erosion protection.

Future work includes the testing of the material system specimens, which will be done in accordance with a modified ASTM G32-98 standard. The modification provides for a stationary sample below the oscillating horn. This modification has been used in many previous studies and provides for easier mounting of composite material specimens. Although the cavitation erosion mechanism present in this method is not the same as that on an immersed moving body, this method has been shown to be useful in ranking various materials with respect to their erosion resistance.

The following is a partial list of initial material systems, which will be considered for the study on cavitation erosion resistance. Based on preliminary background research, these represent some of the most promising composite material systems. A final decision on the material systems to be tested will be made upon further investigation.

- E-Glass/Vinyl Ester laminate
- Carbon Fiber/Vinyl Ester laminate
- E-Glass/Epoxy laminate
- Carbon Fiber/Epoxy laminate

- E-Glass/Vinyl Ester/PVC core sandwich
- Carbon Fiber/Vinyl Ester/PVC core sandwich

In addition to these composite systems, standard materials will be tested as a control.

5. HYSWAC H-body Design

5.1 Single H-body

Navatek started construction of a single H-body for the Waverider. This H-body is a precursor to the H-body to be used on the HYSWAC. The single H-body is constructed using core-cell foam and FRP skins and the internal frame is plywood construction. Expected completion is for 1st quarter of 2002.

5.2 H-Body Design for HYSWAC

The Department of the Navy Office of Naval Research (ONR) is to convert an existing SES 200 vessel in to a dynamically supported, small waterplane area catamaran (HYSWAC). The SES 200 modifications will include extensive renovation of the ship structure and the addition of an H-body. This section summarizes the finite element analysis performed on the vessel presented by Pollard [2001]. Figures 5.1 and 5.2 show pictorial views of the SES 200 finite element model including the H-body.

The principal dimensions of the craft are as follows:

1. Length Overall 47.24m 155 ft
2. Length Waterline (Design) 42.58m 140 ft
3. Beam Moulded 12.99m 42.6 ft
4. Beam Maximum 14.78m 48.5 ft
5. Draught (extreme) 5.77m 18.9 ft
6. Design Speed 30.0 knots 30.0 knots
7. Maximum Displacement 355.6 tonnes 350 Long Tons
8. Deadweight 101.6 tonnes 100 Long Tons

The converted SES 200 is a HYSWAC type vessel. It has a lifting body beneath the main hull, called an H Body, which provides the craft with dynamic lift. The H Body is attached to the main hull by means of two struts, one extending from each of the two catamaran hulls. The H-body is primarily an aluminum structure with composite end caps as shown in Figure 5.3. The structural model of the attachment of the H-body strut to the hull is shown in Figure 5.4.

5.2.1 Finite Element Model and Analysis

The model of the H-body primarily consisted of plate elements, but beam elements were used for some of the stiffening and solid elements were used to represent the main engines and gearboxes (they were modelled as simple brick shapes that approximated to the size of the entities and the material density was factored to give the correct masses). The model of the rest of the vessel was taken from the FE model produced by Rochester Institute of Technology, [RIT, 2000].

The finite element model was subject to the following six load cases:

1. 0.5g acceleration applied transversely on whole craft when underway.
2. 0.5g acceleration applied longitudinally on whole craft when underway.
3. A maximum displacement of 350 Long Tons (LT)
4. A maximum lift force of 350LT plus a 0.5g vertical acceleration.
5. 0.5g x vessel mass applied to the side of the H Body.
6. 240LT lift force applied to the aft foil.

Further details are presented in Pollard [2001]. The three conclusions presented in this report are iterated below as follows:

1. The analysis of the structure of the SES 200 has investigated the response of the vessel to six load cases. Two load cases have been identified as resulting in stress levels close to or above the allowable limits stated in Table 5.1. Load case 6, representing a maximum lift force on the aft foil, is accepted as a transient load and hence the high stress levels may not be fully developed. Therefore, it is not considered necessary to modify the hull structure such that it can withstand this transient load.
2. Modifications to the original hull structure in way of the connection to the strut have been made to achieve acceptable stress levels in the hull. Similarly, local increases to plate thickness in the H Body / strut intersection have been specified to achieve acceptable stress level in this region.
3. No assessment of the buckling strength of the hull outside of the region close to the strut, has been undertaken. Due to the magnitude of the compressive stresses under the worst load case, load case 4, and the thin plate thicknesses generally used, it is recommended that such an analysis be carried out to ensure no buckling failures will occur.

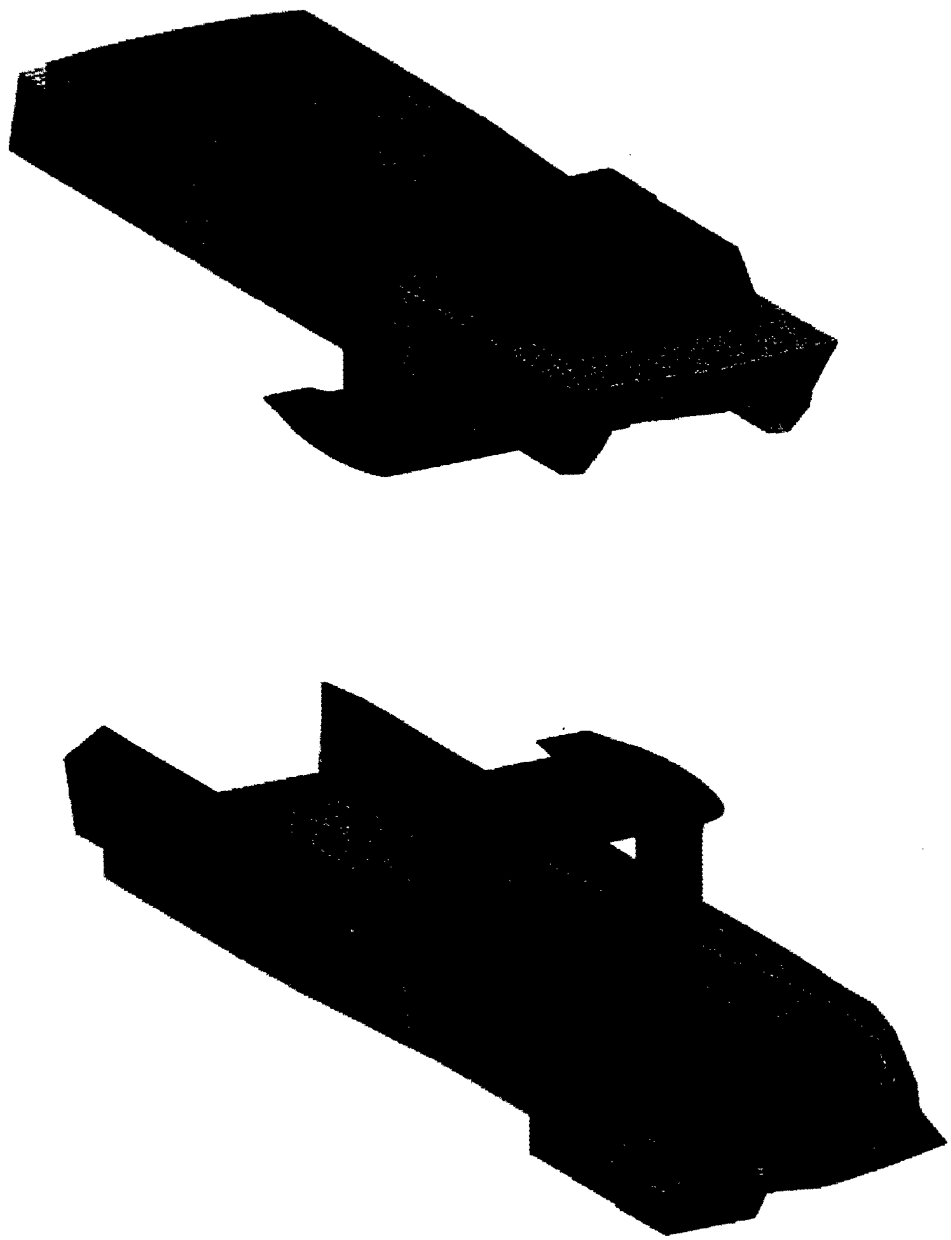


Figure 5.1 – SES 200 Finite Element Model Including the H-body, [after Pollard, 2001].

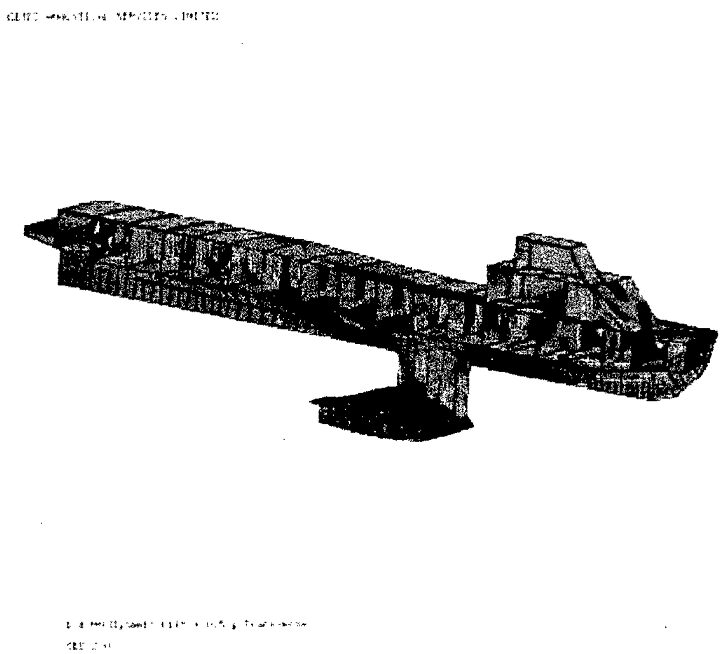


Figure 5.2 –Cut Away of the SES 200 FEM, [after Pollard, 2001].

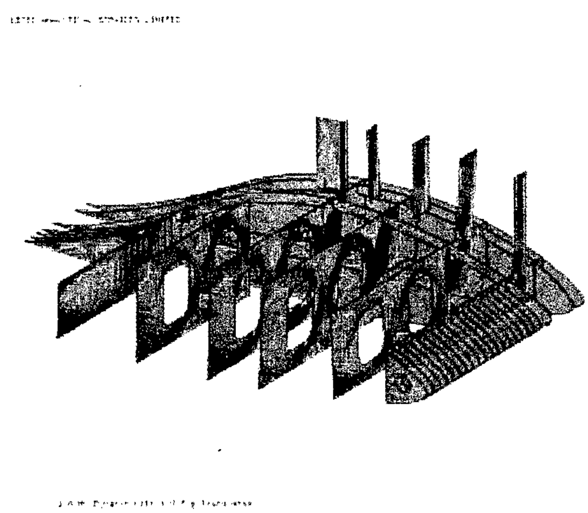


Figure 5.3 –H-body Structure, [after Pollard, 2001].

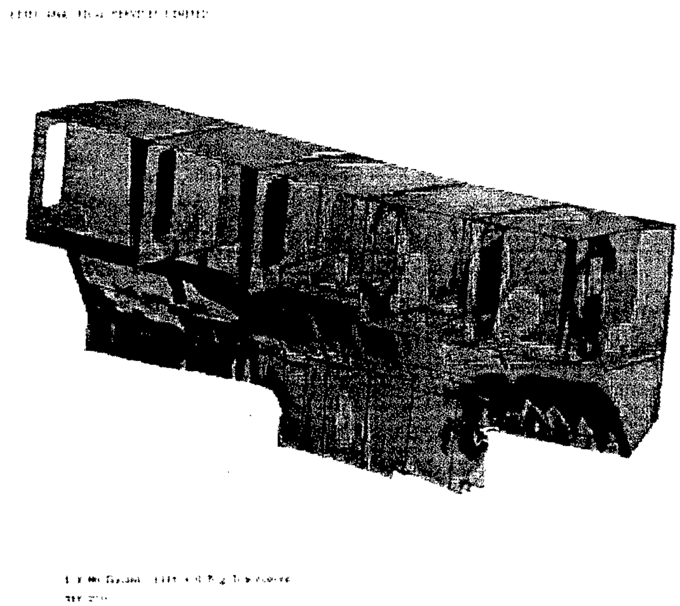


Figure 5.4 –H-body to Ship Interface, [after Pollard, 2001].

6. Summary and Conclusions

Planning was undertaking during this report period for several studies related to connection response. The first is a study of the effects of stress relaxation in bolted connections. This effort will include fabrication methodologies and material systems typically used in Naval vessels. This study will include experimental determination of the effect of bolt torque history, bolt and composite material geometry, stress concentrations, and environment on watertight integrity. Planning for this study is currently underway. Results of pilot testing will be presented in the next quarterly report.

A study of adhesives in hybrid connections is also underway in conjunction with the AHFID program. In this effort the structural response of six adhesives will be compared to each other. Consideration in adhesive selection will be structural performance as well as cost and workability. Tests on lap, scarf and notch joints will be performed. Parameters include the bondline thickness, surface preparation and environmental conditions. Planning for this study is currently underway.

Panel fabrication processes using the VARTM method are currently in place. Several test panels have been successfully fabricated. A plan for material testing of the resulting composite laminate will be developed as well as techniques for manufacture of hybrid connections.

Studies for cavitation erosion protection have been initiated. A simple and inexpensive experimental setup used for down-selection of materials has been developed and implemented. This setup is based upon ASTM G32-98. Preliminary test data will be forthcoming in the next quarterly report.

Design and construction planning of the H-body for the HYSWAC is progressing. A complete finite element analysis of the H-body by CETEC has been completed and a report submitted. This analysis includes a global analysis of the SES 200 plus the underwater H-body. Results of the finite element analysis to five load cases is presented. Construction of a single H-body for the WAVERIDER has commenced. This is a relatively small body constructed using internal plywood frames and FRP skins over core-cell foam.

7. References

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3. Plesset, M.S. and Chapman, R.B. (1971). J. Fluid Mech. 47, 283-290.
4. Pollard, M.R., [2001] "SES-200 Global Finite Element Analysis Report", CETEC Consultancy Limited, Romsey Hampshire, England, Report No. CET/0617/R/01, 20pp.
5. RIT, [2000], Finite Element Analysis of SES-200, Rochester Institute of Technology, published by the National Center for Remanufacturing and Recovery in 2000.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*: 03-01-2002

2. REPORT TYPE: Progress Report

3. DATES COVERED *(From - To)*: 1-October-2001 to 31-Dec-2001

4. TITLE AND SUBTITLE

Modular Advanced Composite Hullform Technology (MACH) - Progress Report for Quarter 2

5a. CONTRACT NUMBER

5b. GRANT NUMBER: N00014-01-1-0916

5c. PROGRAM ELEMENT NUMBER

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

6. AUTHOR(S)

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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

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5717 Corbett Hall
Orono, ME 04469-5717

8. PERFORMING ORGANIZATION REPORT NUMBER

UM-MACH-PR-01-2

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Office of Naval Research
Ballston Center Tower One
800 North Quincy St.
Arlington, VA 22217-5660

10. SPONSOR/MONITOR'S ACRONYM(S): ONR

11. SPONSORING/MONITORING AGENCY REPORT NUMBER

12. DISTRIBUTION AVAILABILITY STATEMENT

Approved for Public Release, Distribution is Unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

This progress report summarizes the second quarter of work on the Modular Advanced Composite Hullform (MACH) project.

15. SUBJECT TERMS

Composites; Hybrid Structures; Connections; Structural Monitoring

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
U	U	U	UU	23	Vincent Caccese

19b. TELEPONE NUMBER *(Include area code)*: (207) 581-2131

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI-Std Z39-18